Chapter 7
Machinery During the Industrial Revolution

To attempt to cover machine developments during the Industrial Revolution in just few pages is as absurd as it is impossible. This period of our history arose after the knowledge of previous eras had been accumulated and through a combination of a series of factors that resulted in a period of continuous advances and progress that ended up in a change of approach both in society and engineering, with technical developments of huge quantity.

The construction of the steam engine was a key point, but maybe more at an engineering level as it established a concept: "We don't need men for work, we have a machine". This phrase stated very simply the search for automation in any field, like in agriculture, mining, or the textile industry where machines began to substitute people as a result of the newly discovered technologies.

Thus, there are many people who contributed to this development that not even the largest encyclopedia could describe with so many details. Thus, some of the most significant achievements have been outlined by using beautiful illustrations that are contained in the books on machines of the long fecundus period of the Industrial Revolution.

During the Industrial Revolution, all the fields of technology were improved with a velocity that had never been experienced in the past, although none of them actually had a predominant role, not even the invention of the highly renowned steam engine. These developments may have had a specific influence on and were achieved because of the Theory of Machines and Mechanisms as a result of a society whose needs were increasing day by day.

On Textile Machinery

One of the technologies that experienced greatest changes was the textile industry. In a very short time after 1770, textile industries became divided into those that possessed technology and machinery and those that continued to use manual and antiquated techniques. In order to get an idea of the change, it is worth referring the fact that in 1760 the London "Society of Arts" called for a competition for the best

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invention of a machine that could be capable of spinning six threads at the same time with the aid of only one person. Technological progress was the name of the game.

In 11 short years, the textile industry was flooded by three machines that brought radical changes to production, namely Arkwright's "Water frame" (or continuous motion machine) that was patented in 1769, Hargreaves' "Spinning Jenny" that was patented just a year later, and Crompton's "Mule" in 1780.

It is probably Arkwright, who most made possible great developments in the textile industry with the machine illustrated in Fig. 7.1. For the first stage of spinning (which has three stages: stretching, twisting, and winding) he invented grooved rollers that continuously stretched the thread.

Hargreaves invented the double carder with the following characteristics: two cards were placed in a normal spinning wheel, one attached to a frame and the other moved by ropes and pulleys so that twice as much work was done. Figure 7.2 shows a further development of this first machine with 12 cards six of which were static and six were mobile. It was not long before "jennies" with up to 100 spindles were built.

Then, Crompton's machine was a result of combining these two machines together. From that moment in textile factories, machines as complex as the 1860 "mule-jenny" in Fig. 7.3 were installed in large numbers. It can be noted how the multiple spindles are located at the left of the machine and how the threads are stretched by means of distance and the grooved cylinders to the right.

After spinning, the next job was weaving. The most outstanding machine for this task was invented in 1801 by Joseph Marie Jacquard. Based on the advances by Bouchon and Vaucanson, he built a machine called the "Jacquard", which worked with the use of perforated cards to weave different patterns of cloth. This perforated card had the task of automatic weaving. Later this idea helped Charles Babbage

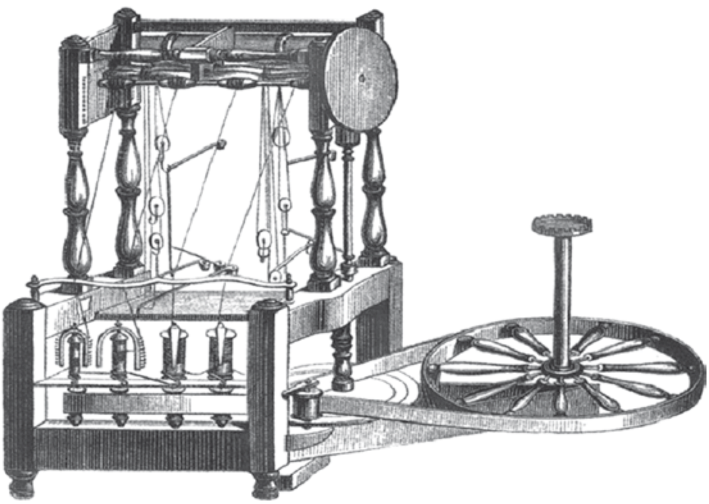

Fig. 7.1 Arkwright's water frame

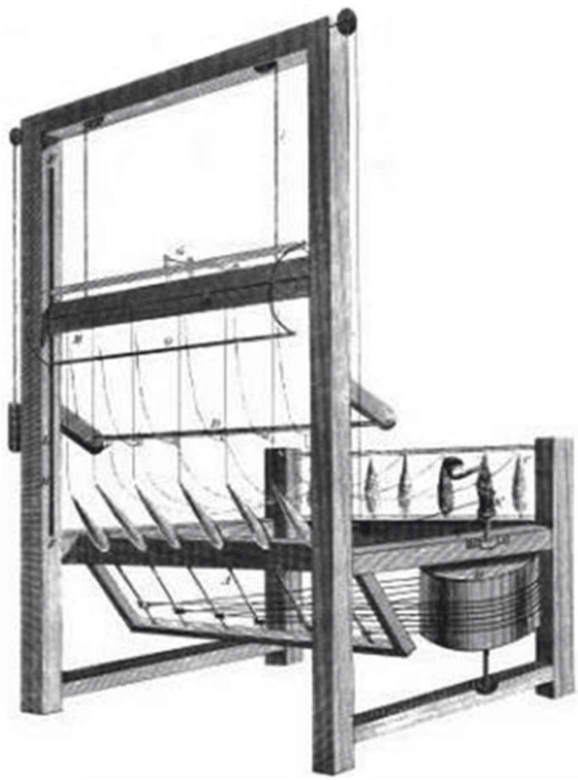

Fig. 7.2 Hargreaves' "Spinning Jenny"

develop his idea of a mechanical universal calculator, which was the precursor of modern computational methods.

Figure 7.4 shows a picture of Jacquard's loom. The man sitting in front of the machine had only to pass the threads and to choose the card for the cloth. Once this operation is performed, it was sufficient to operate the lever that made the threads run and transform them into the cloth that emerged from the top with the required intricacy of threads.

The next stage after weaving was sewing. Bartholomy Thimonnier created the first sewing machine, since he is usually quoted as the inventor, because in 1830 he obtained a patent from the French government to use a latch needle. His machine is shown in Fig. 7.5. It can be noted how the thread is fed to the needle by a sequence of pulleys and springs and it perforates the cloth to produce a chain stitch seam.

One of the sewing machine's main parts is the loop-taker or shuttle. The thread passes through the cloth forming a loop under it. The loop-taker catches it as the needle withdraws and goes on to pierce the cloth again when it has moved forward. The new loop then enters the old one and thus the sewing is completed. One or two threads are used depending on the type of machine.

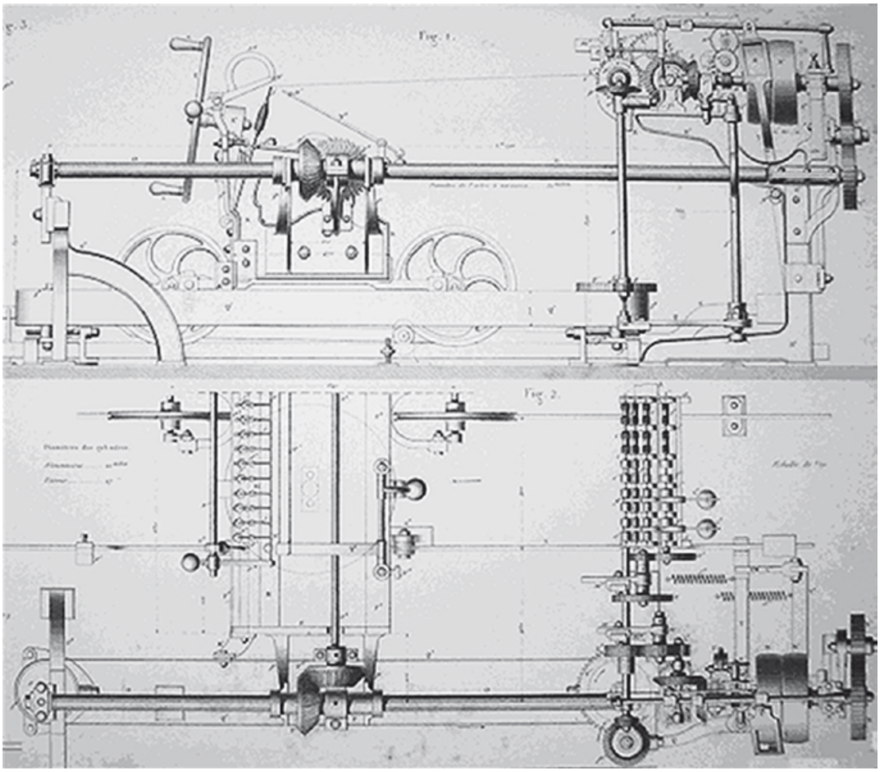

Fig. 7.3 The 1860 spinning mule [124]

Elias Howe's machine was the next new one and appeared in the United States in 1844, and some years after, Isaac Singer (1851) produced an improved version.

Many were the advantages of the new sewing machines: the work became automatic, the stitching was regular and there was a minimum waste of thread. One of the main problems was to obtain a continuous thread so that an almost unlimited number of stitches could be sewn rather than just being able to sew a small piece of material. Thimmonier's machine did not obtain continuous work, but Howe's (Fig. 7.6) and Singer's machines had a spool pin that the thread could be placed on so that the machine would pull on it at each stitch, the length of material to be sewn being proportional to the thread that was fitted on the spool.

The principles of sewing machines have remained unchanged to the present but some changes have been made to the automation of the processes in relation to the machine's efficiency and speed. Originally handle-operated, it is now pedal-operated so that the hands can remain free (in Fig. 7.6, the machine is operated by pulley V). Finally, sewing machines were designed to be driven by a foot-operated electric motor.

Howe's machine is operated by a cylinder C whose grooves serve as a guide for the main thread and the head for the hook. Figure 7.7 shows the head of the more

Fig. 7.4 The Jacquard loom

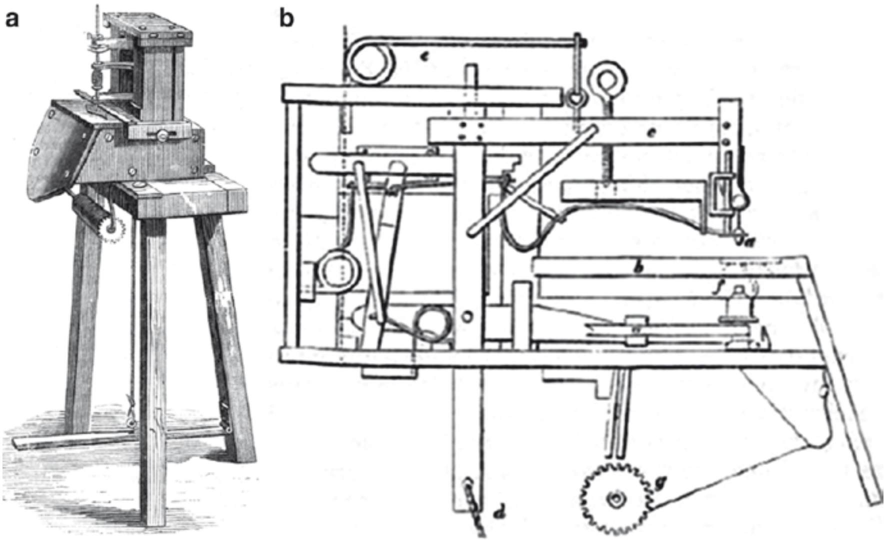

Fig. 7.5 The Thimonnier sewing machine [90]

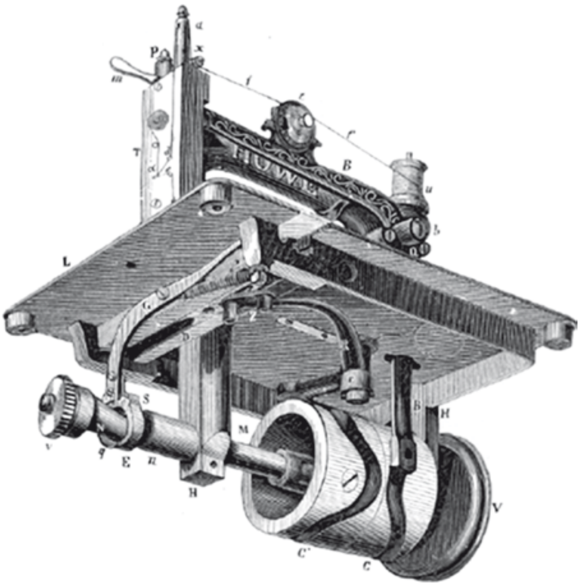

Fig. 7.6 Howe sewing machine [90]

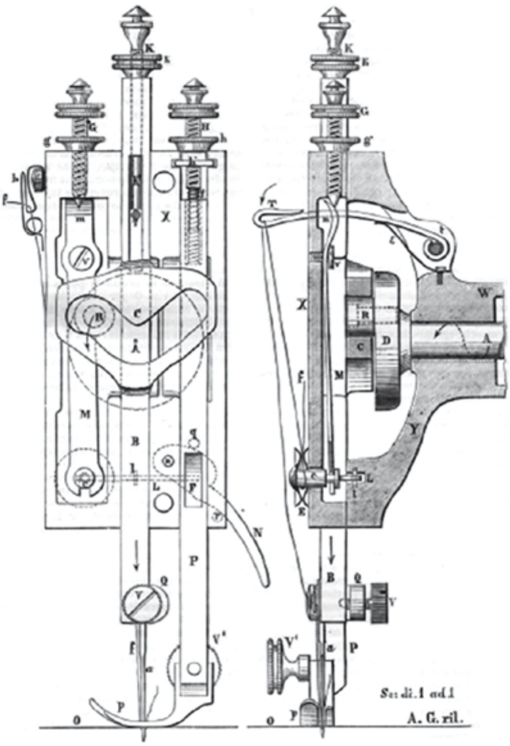

Fig. 7.7 The Singer machine head [90]

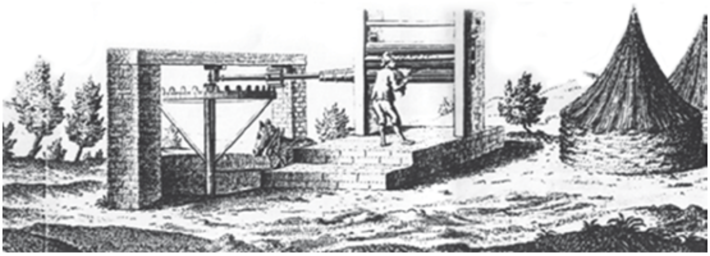

Fig. 7.8 Hemp and flax fibre softening machine [104]

advanced Singer machine. The thread is tensed by a hook, which can be positioned to obtain different types of stitches.

Frequently used materials were hemp and flax. In 1874, Salvá and Sanponts, both medical doctors, wrote a dissertation on an explanation and use of a new "machine for processing hemp and flax fibre" where there is a detailed explanation of the construction and features of their machine, by stressing all the benefits as compared to previous machines.

The machine, which is shown in Fig. 7.8, is driven by a horse which rotates a 72-tooth horizontal wheel. Then, this wheel drives a 12-spindle lantern which turns the grooved rollers whose job is to crush and stretch the flax and hemp. The operator's job consists in feeding the hemp and flax fibres through the rollers; then, he collects them, as can be seen in the illustration. The grooved rollers were located so that they remained separated when no flax was fed through them in order to avoid grinding or wear. In addition, when they were working, they could come together to press the flax or hemp as tightly as possible for optimum results.

Referring to the benefits of their machine, the authors stated: "Our machine not only corrects the evident defects of the Fibre Softener, Cutter, and Mill, but also, at one and the same time, performs the three operations of softening the fibres, and cutting and milling the flax".

On the Evolution of Handcraft Manufacturing

In the previous chapters we have discussed how the saw machine, of great importance for mankind, evolved. The last examples recall the saw mechanisms designs by Francesco Di Giorgio or Jacobus Strada. During the Industrial Revolution, several innovations were proposed for this machine.

Figure 7.9 is a design by Berthelot, who in 1782 drew this illustration of a wood saw. It had an up and down movement that is produced with the aid of a dual rack pinion. This provided the saw with vertical movement while the wood was moved horizontally by a vertical wheel-pulley system with a rope that moved the platform where the trunk was installed.

The second is the saw by Forest de Belidor. He was a French engineer who worked in several fields, including war machines and mathematics.

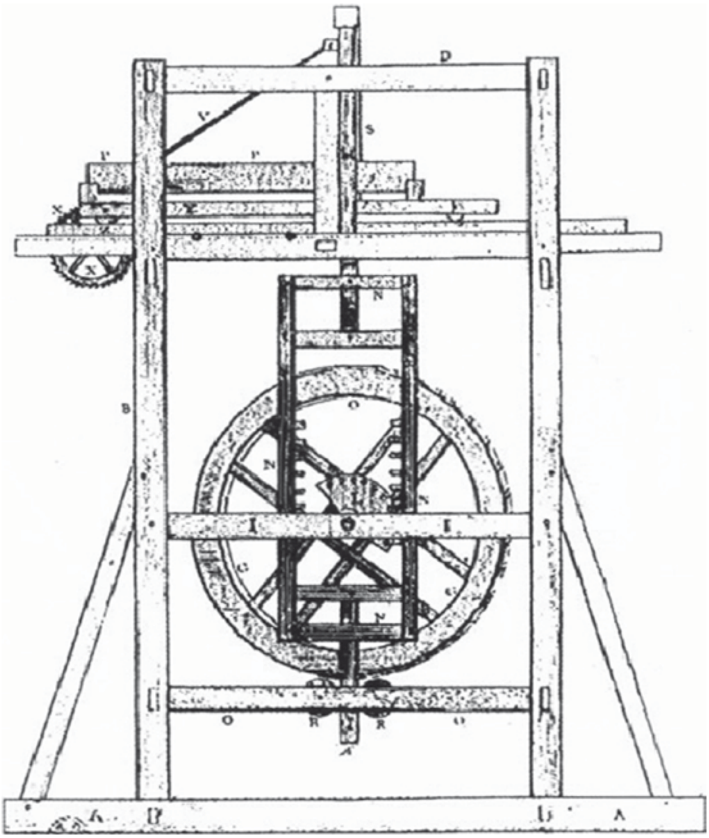

Fig. 7.9 Berthelot's wood saw [112]

Figure 7.10 shows a more advanced saw than Berthelot's, as it is dated 1787. It was also hydraulically powered but with the vertical movement that was transmitted by a crank and the horizontal forward movement of the wood was guided by three articulated rods and a wheel. This wheel had a smaller gearwheel that engaged the base supporting the wood so that when engaged, it provided the forward movement (right-hand side of the figure).

Only 5 years had passed between Berthelot's and Belidor's saws but the differences in appearance and design are considerable. The meticulous details in the drawing by Forest de Belidor indicate it is the result of an intense in-depth study of the mechanisms that was required to gain the best performance and productivity. This Belidor drawing makes Berthelot's saw seem rather crude and unpolished when the two drawings are compared. Just 1 year later, in 1788, Casado de Torres built a new saw but this time he made use of the newly invented steam engines to drive it.

In order to diversify the sawing work, Casado de Torres produced two saws, as shown in Fig. 7.11. In the first (on the left) he installed a series of parallel blades

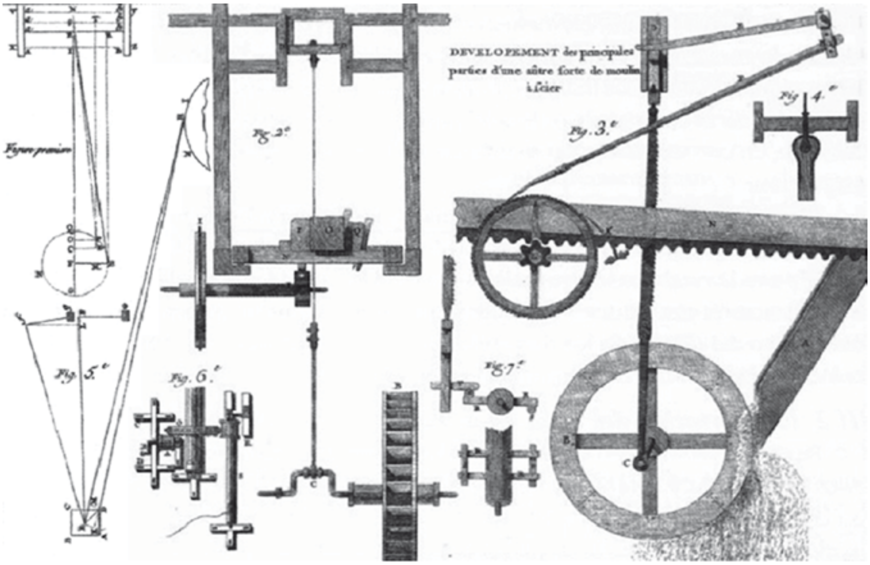

Fig. 7.10 Forest de Belidor's wood saw [112]

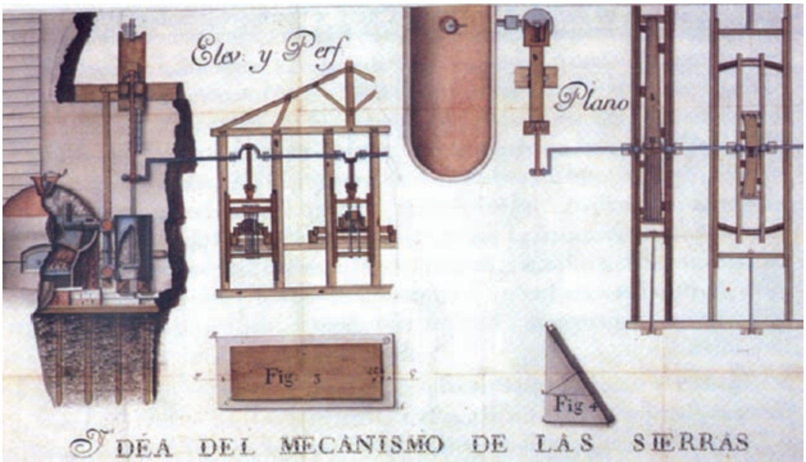

Fig. 7.11 Casado de Torres' wood saw [112]

to obtain strips of a thickness that could be obtained by the separation between the blades. In the second (on the left) he installed a turntable so that the wood could be turned to obtain curved saw cuts.

This is an excellent example of how to multiply the work by using only a single source of energy. The crank is connected to two rods, each belonging to a saw working in the opposite direction in order to balance the movement. The perfection and details

of the drawing should also be noted, with diagrams showing a general view, elevation, and cross-section of the machine with as much information as possible, including exact geometric relations and dimensions so that the machine could be physically built without any assistance from the designer. Progress was experienced not only in the way how the source energy operates a machine but also in the way how the work is multiplied and increased in diversification of the end-products. Instead of one strip of wood, ten or more pieces could be cut and, if required, the wood could be turned to get a curved cut. Moreover, just one person was needed to supervise the operation and position the wood without any more effort required of them.

Figure 7.12 illustrates a press that was designed by J. Bramah in 1795. It had a dual mechanism where pressing was performed in a spring-loaded piston. This spring was, in turn, operated by a crank handle.

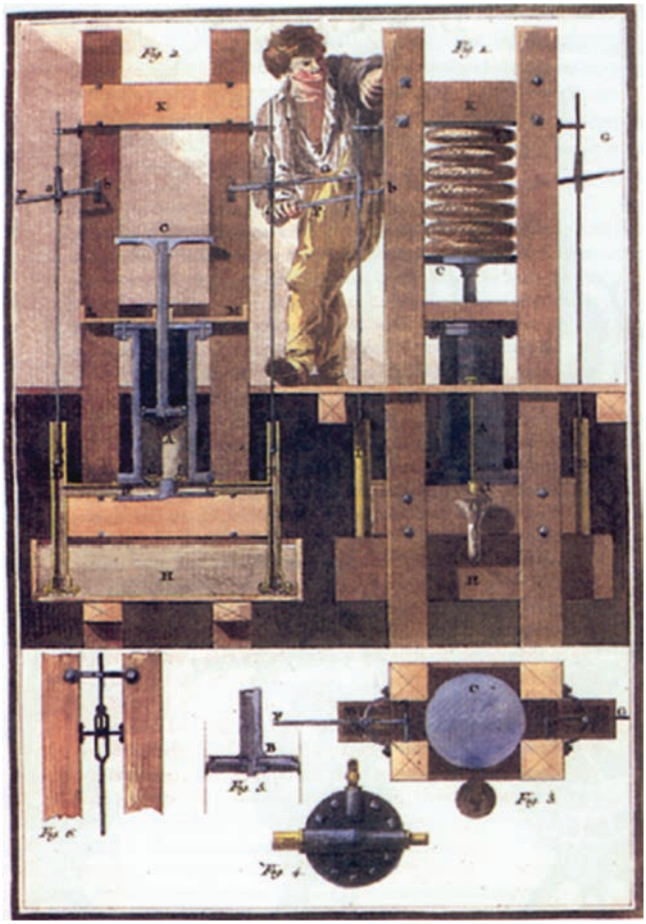

Fig. 7.12 J. Bramah's press [112]

On Machine Tools

The different types of saw and press machines previously illustrated are linked to the machine tools that were developed in the form of huge machines for the basic operations of cutting, drilling, grinding, and polishing.

The Industrial Revolution identified the need for a new kind of machine namely for mass production. Industrial machine tools had specifications and features that were needed for mass production and with long duration. The first machine of this type may be attributed to John Wilkinson who, in 1775, built a vertical drilling machine. Then, in 1794, Henry Maudslay developed an industrial mechanical lathe.

Figure 7.13 is a vertical lathe with three rotary heads that are useful to facilitate movement. The illustration shows the size of the machine compared to an operator.

Around 1860, the pages of machine tool books, magazines, and catalogues included lathes, milling machines, drilling machines, grinders, and boring machines. This gives some idea of how these types of machines had greatly evolved over a century.

Figure 7.14 illustrates a drilling machine, which is capable of making holes at an angle by partially rotating the tool. The hole height could also be changed. Even the entire body of the machine could be rotated as a characteristic that was extremely useful for large machines that were difficult to move. It is evident how machine tools increased in complexity over the years with the mechanisms that added accuracy, comfort, and efficiency to the machine operation and application goal.

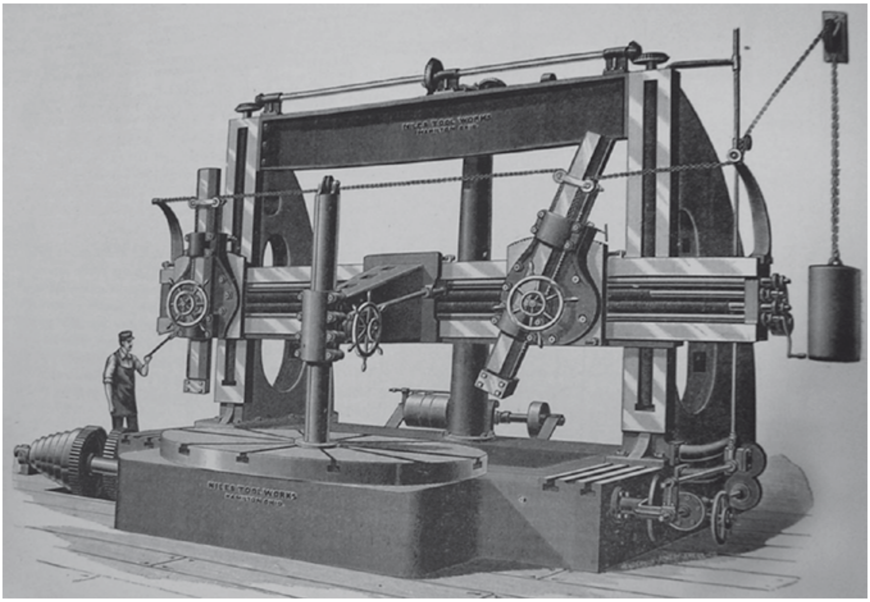

Fig. 7.13 Vertical lathe [101]

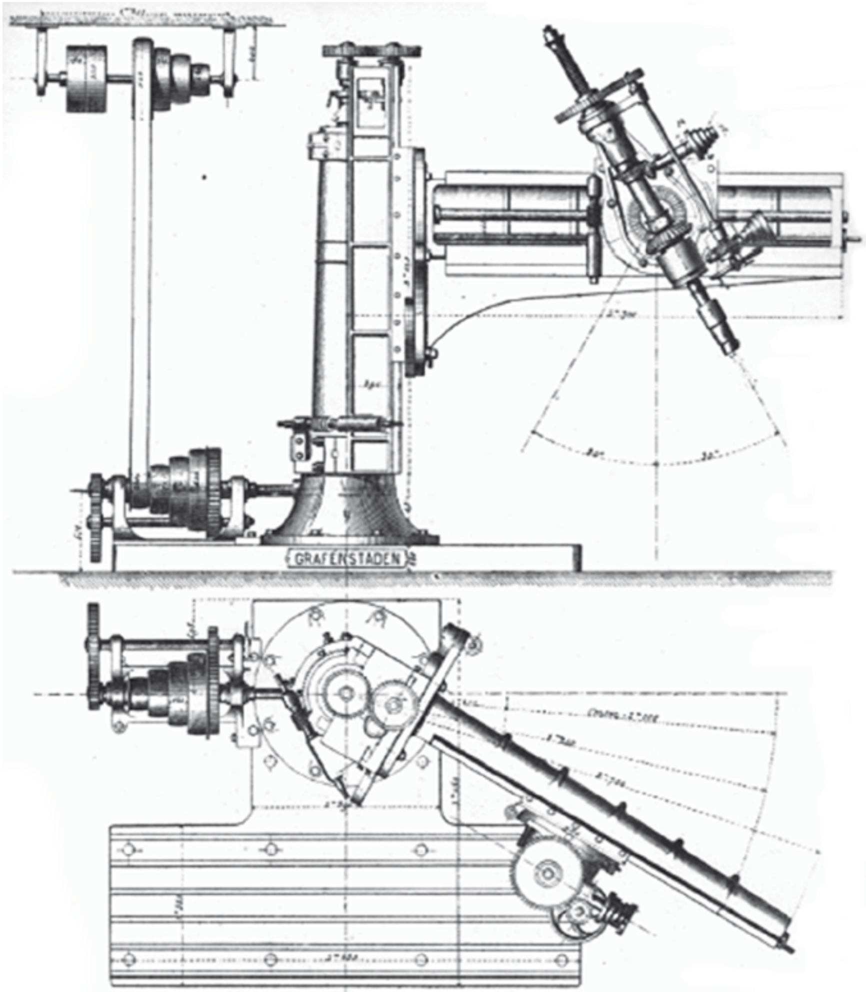

Fig. 7.14 Drilling machine [101]

On Hydraulic Machines

In previous chapters, successful hydraulic machines have been discussed as based on mechanisms to raise water to the required level. But further developments were proposed during the Industrial Revolution too.

One of the greatest design was by Louis XIV's engineers who produced the "Marly Machine", a huge civil engineering work, which in 1684 succeeded in supplying water to the Palace at Versailles by using 14 paddle wheels. Figure 7.15 shows a painting of the machine and Fig. 7.16 shows a cross-section of the paddlewheels. These wheels drove 64 pumps that raised the water almost 50 m. There was a second

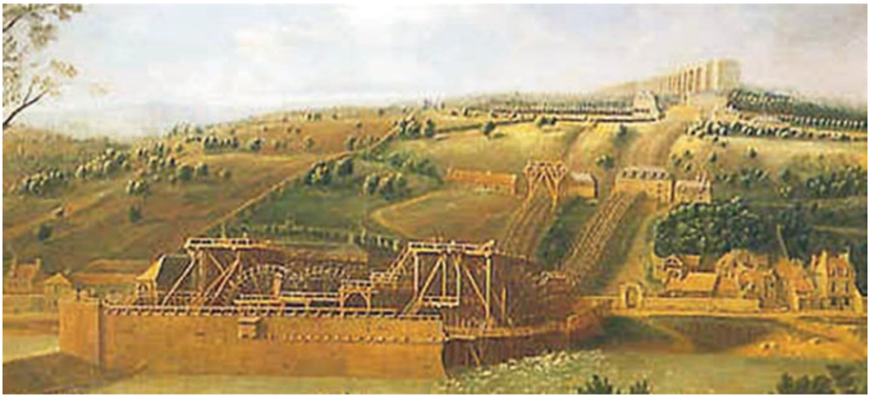

Fig. 7.15 Part of a painting of the “Marly Machine” at Versailles

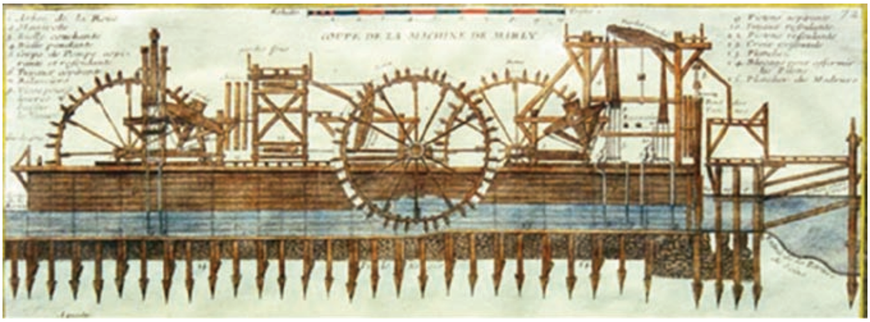

Fig. 7.16 Cross-section drawing of the “Marly Machine”

reservoir that contained another 69 pumps which again raised the water more than 55 m, and then a third stage of 78 pumps was used to raise the water up to the aqueduct that channelled the water to Versailles.

Figure 7.17 shows a bird’s-eye-view of the set of wheels and pumps, which gives an idea of the overall size. Figure 7.18 gives a more detailed illustration of the action of a paddlewheel on the suction piston.

During the Industrial Revolution, the paddlewheels were replaced by much more efficient steam engines that took up much less room.

It is clear that during the Industrial Revolution this kind of machine benefited from the widening scope of mechanical know-how with the invention of machines that were more intelligent and with better technical specifications, like those in Fig. 7.19 showing Prunier’s hydraulic system. It was built to supply the generators at the 1784 Vienna Universal Exhibition with water raising 14 m above the ground. In Fig. 7.19, the system is composed of two vertical suction pumps next to two

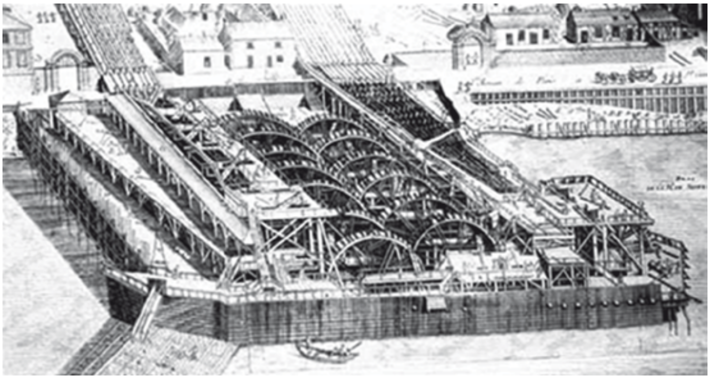

Fig. 7.17 Bird's-eye-view of the "Marly Machine"

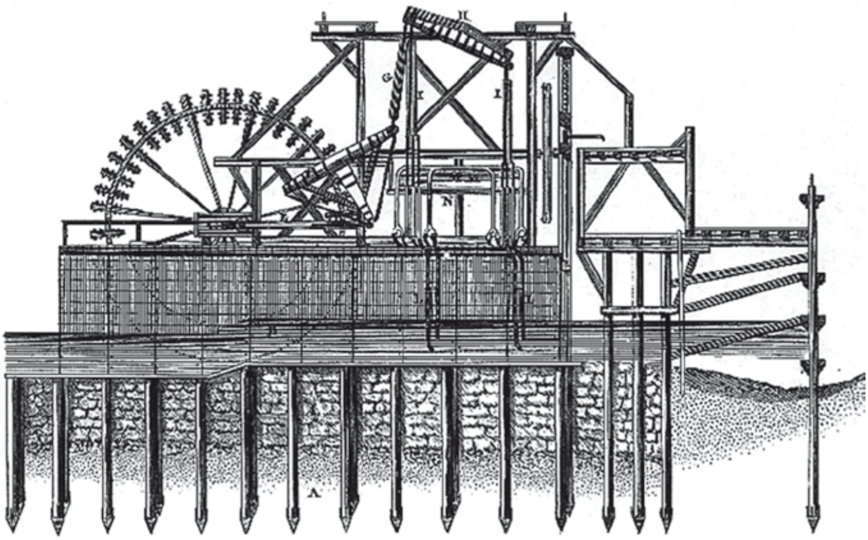

Fig. 7.18 Detail of the "Marly Machine"

steam engines. What made this machine original was its capacity to work by using both pumps together or, alternatively, to use a single but efficient mechanism.

In order to collect water from the Danube with this pumping system, 17-m long pipes were installed with 1 m diameter. In order to raise the water into the pipes, two pistons were used within which the two cones in the illustration were included. These cones had two rings, which let the water to flow down stream, and they closed the flow in the other direction of the piston up-stroke to retain the water. In the illustration, the elevator on the left is at the down-stroke position while the one on the right is completing the upstroke. The pumps were operated with a perfectly balanced alternate motion so that there could be a continuous flow of water from the centre pipe.

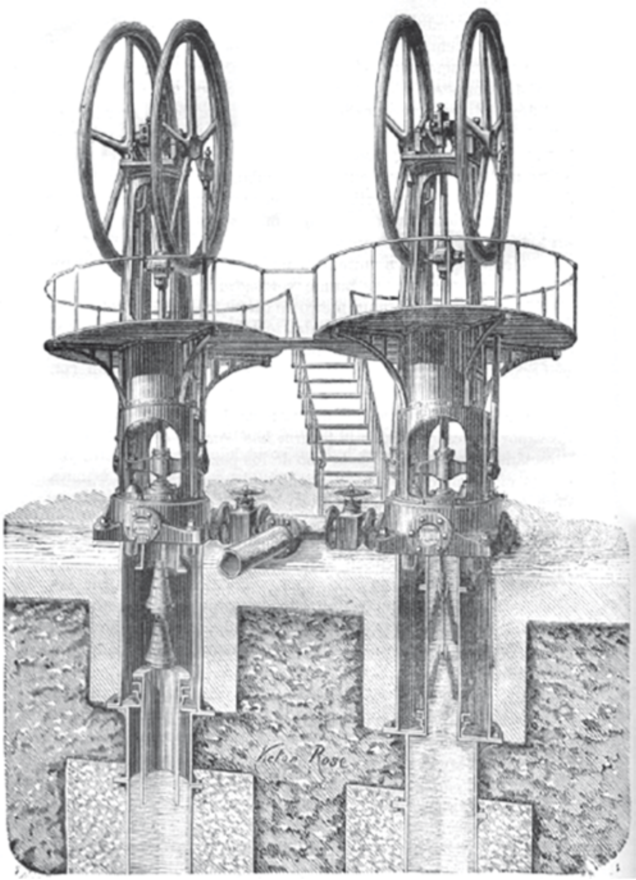

Fig. 7.19 Hydraulic machine at the Vienna Universal Exhibition, 1874 [6]

Let us now take a look at the history of turbines. This began with water-wheels in Egypt and China, but strictly speaking, the theory of water turbines began with Euler (1754) when the construction of Fourneyron (1827) was successfully achieved. Two type of installation for water turbines were considered, namely a horizontal wheel, as shown in Fig. 7.20a), and a vertical wheel, as shown in Fig. 7.20b).

On Steam Engines

The usefulness of steam is based on its performance. According to texts of the time, “A quintal (~46 kg) of coal carefully used produces an amount of work that is greater and more regular than that of 12 strong, tough men”. This statement makes

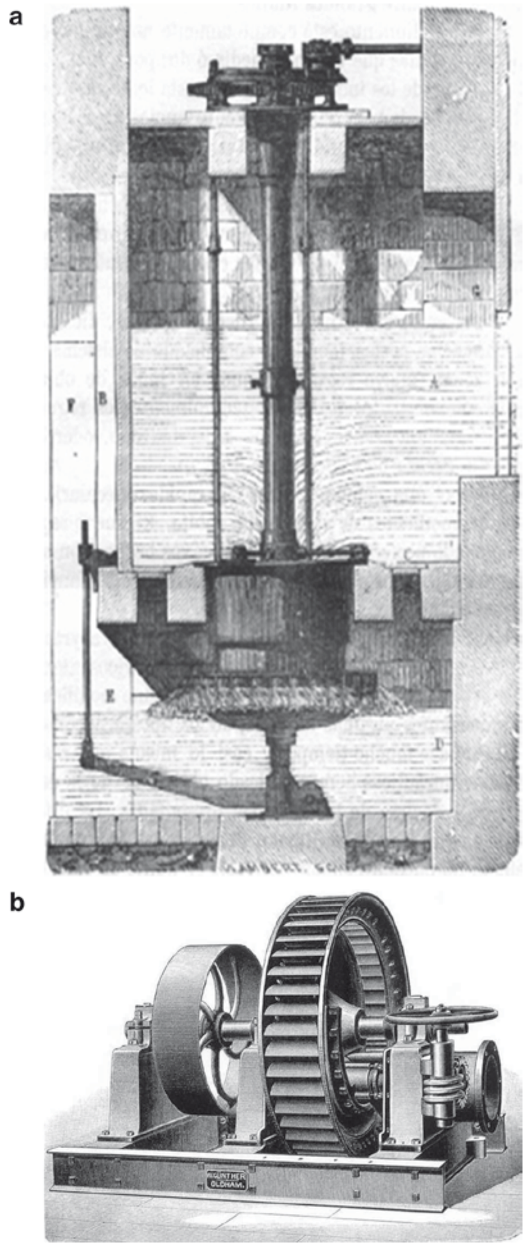

Fig. 7.20 (**a**) Horizontal wheel turbine from the Vienna Universal Exhibition, 1874 [6]. (**b**) Vertical wheel turbine, 1890 [105]

it quite clear that the steam engine and the use of coal as an organic propulsion material had become an absolutely necessary aid.

As already stated, the first sketch of a steam-driven machine was by Hero of Alexandria and it was not until 1606 that this method again began to be studied by Jerónimo de Ayanz, and by Giovanni Branca in 1629.

In 1673, Denis Papin (1647–1712) and Christian Huygens (1629–1695) proposed a steam engine, but it was Thomas Savery (1600–1715) in 1689 who used steam to extract water from the mines with his "miner's friend" that is shown in Fig. 7.21.

However, Savery's engine had several drawbacks: the engine was located about 12 m underground and the pressure reached ten atmospheres, which meant the pipes had frequent failures. Nevertheless, the illustration shows Savery's principal, which was that vacuum was created in the containers for raising the water without the aid of pistons.

When the complications of Savery's engine were clearly experienced, Newcomen studied them and designed a new engine, as shown in Fig. 7.22, which he revealed in 1712. This used a piston that was moved by the vacuum that was created by the

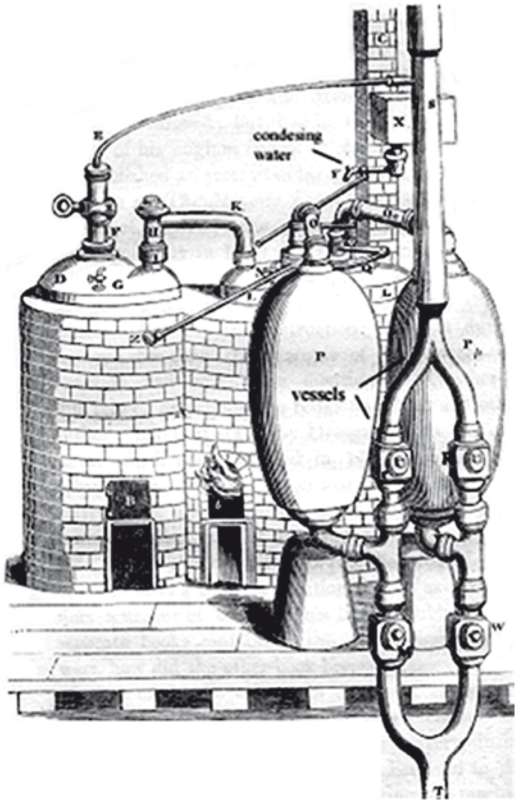

Fig. 7.21 Savery's steam engine

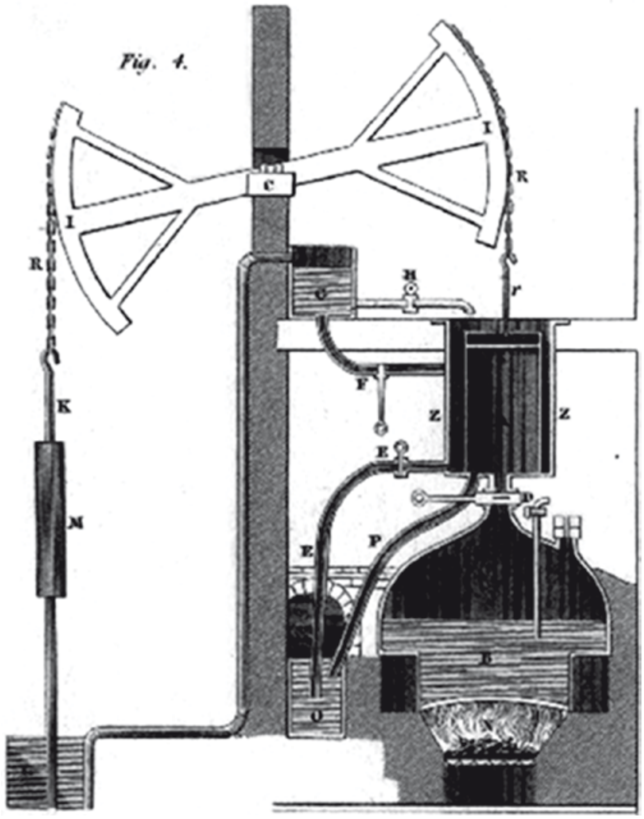

Fig. 7.22 Newcomen's steam engine

condensation of the steam. This piston moved the large pulley to the left that raised the water. This machine could reach 12 strokes per minute with the aim of raising 45 L of water from a depth of 46 m at each stroke.

The ultimate steam engine was designed by James Watt (1739–1819). In 1769, he conceived an engine that was a considerable improvement on Newcomen's design, since it reduced the steam losses and increased mechanical performance. The way to achieve this was simple: Watt condensed water in another cylinder that was distinct from the drive piston, by connecting both with a pipe and by covering the piston with a steam jacket to preserve the heat. Watt added other improvements with the centrifugal regulator by using balls for speed control and by obtaining rotary motion instead of linear motion, as shown in Fig. 7.23, where the engine turns the wheel on the left by means of the articulated rocker arm at the top with a connecting rod that moves a gear assembly at its lower end to connect with the drive wheel. This planetary gear was one of the five solutions that were patented by Watt to obtain circular motion as machine output.

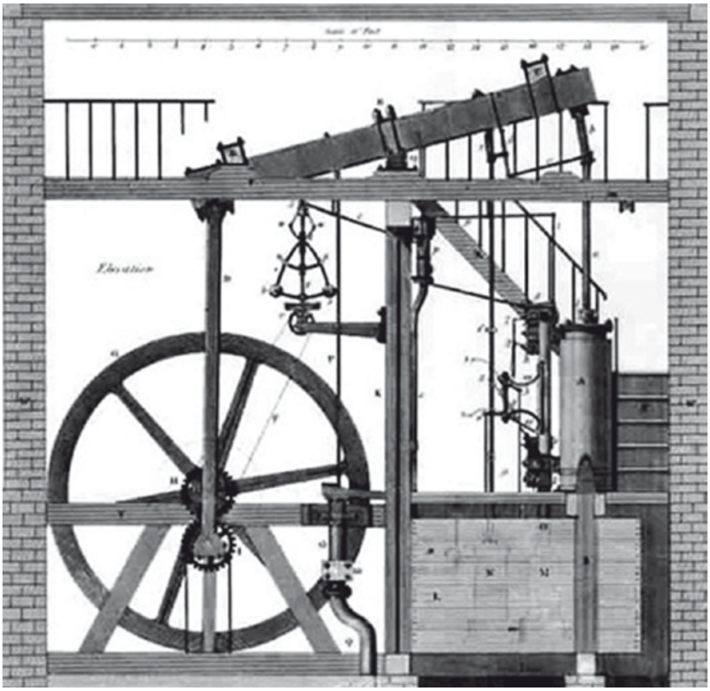

Fig. 7.23 Watt's steam engine

Watt continued working on his engine by making more improvements. He owed part of his success to Wilkinson, who in 1775 invented a cast-iron drilling machine that was precise up to 1 mm. This meant that heat losses from the steam engine were greatly reduced and Watt began to propose building a double-acting engine. With this success, Watt began to pride himself on his new invention: the so-called "Watt's singular mechanism" and its later extension "Watt's extended mechanism". This mechanism consisted of an articulated four-bar linkage that can be seen in Fig. 7.24, as a drawing of one of Watt's double-acting engines by Agustín de Betancourt. The articulated mechanism makes the piston to generate the rotary motion of the wheel on the right during both the upstroke and downstroke piston action.

British progress also reached Spain, but somewhat later. In 1813, Jorge Juan designed the single action steam engine as shown in Fig. 7.25. The illustration shows it to be a water-raising device as based on straight-line vertical motion.

From 1850, the main concern was to increase engine power, which gave rise to various constructions, like O. Patin's whose advertisement for his engine is shown in Fig. 7.26, as it appeared in machine magazines in 1860. Machines like the one in Fig. 7.27 were also built with triple-expansion or smaller engines for work requiring smaller power.

When the steam engine had reached the above successful general developments, engineers were attracted to individual parts design or constructional details in order

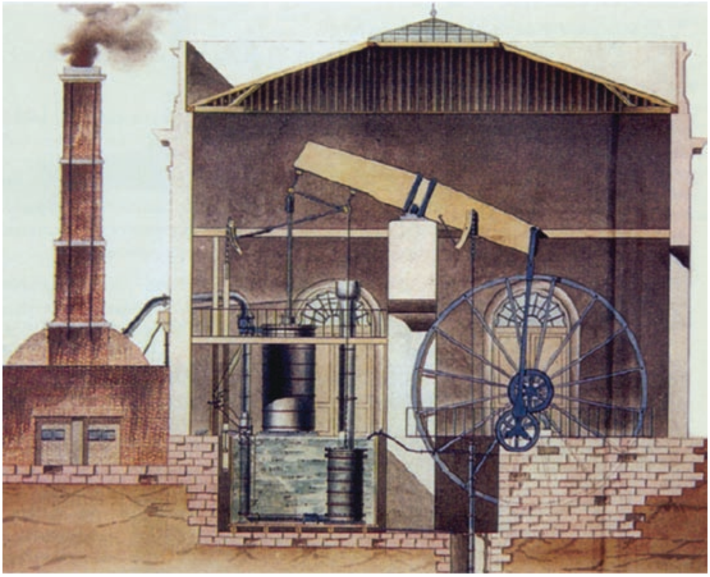

Fig. 7.24 Watt's double acting steam engine [112]

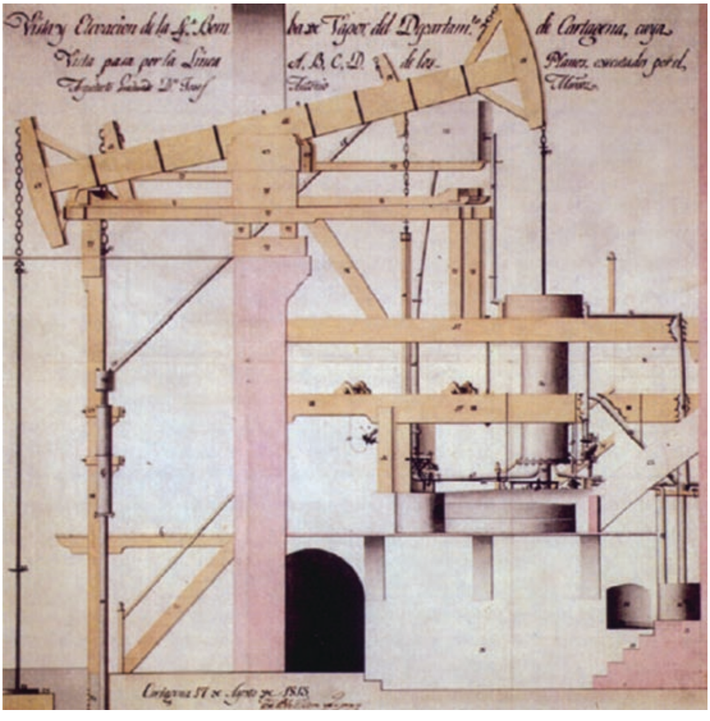

Fig. 7.25 Jorge Juan's single-acting steam engine [112]

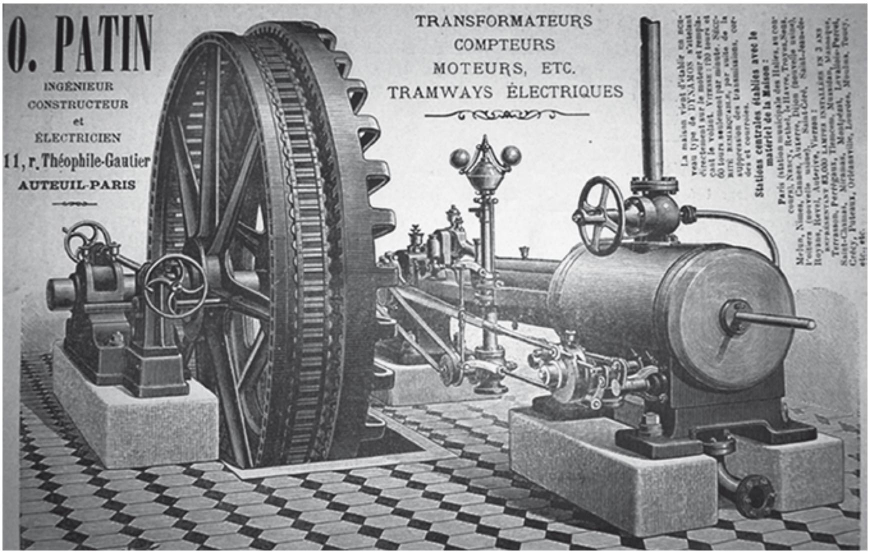

Fig. 7.26 O. Patin's steam engine advertisement [101]

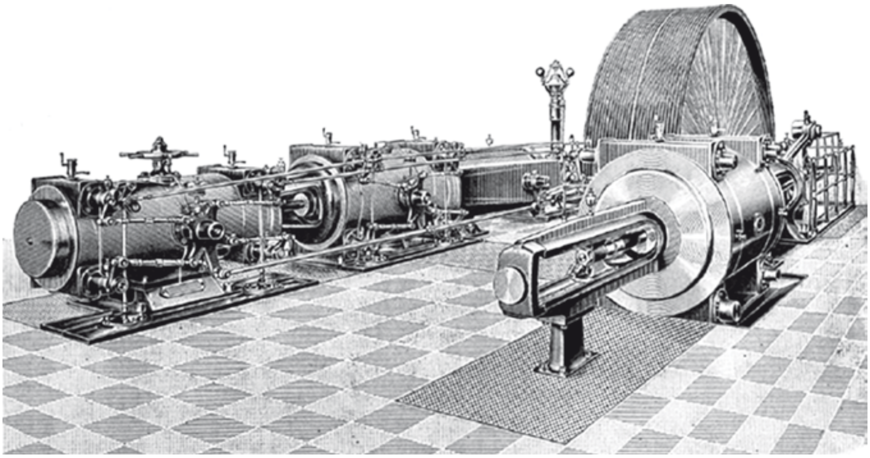

Fig. 7.27 Triple-expansion steam engine [106]

to add some improvement or innovation. This led to many layouts and changes that were experienced as shown in the example of Fig. 7.28 in which a steam engine is proposed with two pistons instead of one with a V-shaped layout to save space. This engine was built in 1879, over 100 years after Watt had built his double-acting engine. The illustration shows an amazing development in the technology of the engine as well as in aesthetics and size. It should not be forgotten that the

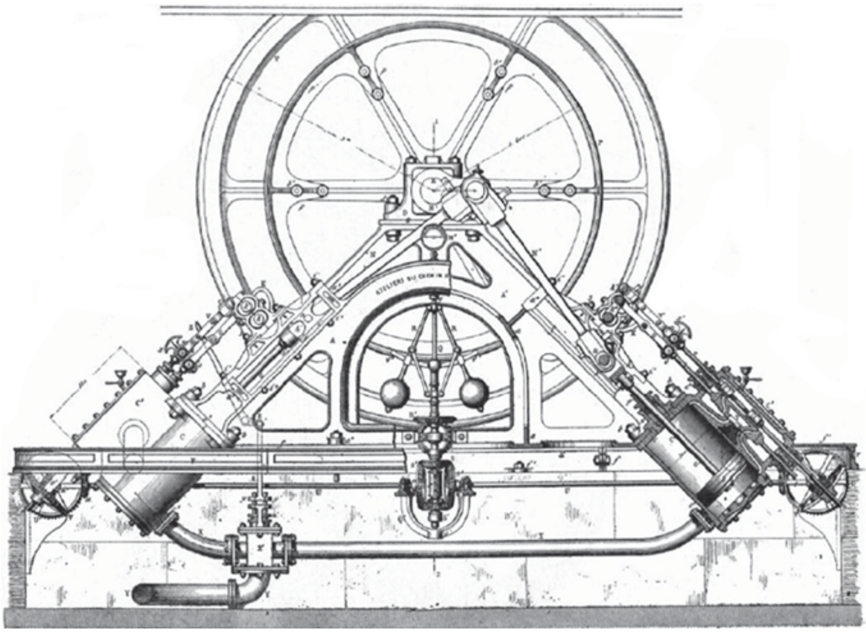

Fig. 7.28 Slanted cylinder steam engine [106]

improvement in the different engine parts was aided by the improvement in machine tools, as previously mentioned.

Those developments gave a great variety of engines that tried to excel in the different qualities demanded by consumers. After the steam engine came onto the scene, one of the priorities was to reduce its size to make it "domestic". There were many families that could use a steam engine at home to do the harder jobs, so that the children or women could supervise the work while the men worked outside the house.

Thi is the case of the vertical steam engine in Fig. 7.29. Its inventors (The Buffaud Company in Lyon, 1874) made it in this configuration so that it could be moved around the house, since the boiler could be rotated. Moreover, the boiler was small and the water pipes were installed so that they could be easily replaced.

Among the engines that were exhibited at the 1874 Vienna Universal Exhibition, the one in Fig. 7.30, that was manufactured by Frederick Siemens, attracted the greatest interest. This engine design introduced a radical change as compared to Watt's conception of a steam engine, since it had no piston connecting rod or crank and its external appearance was more like that of a screw. The innovation consisted in the engine's rotary motion and at no time did the steam escape to the outside. The engine was started by filling the bottle labelled A with water through an hole in the neck which was closed once the water was inside. Then, the lower part of the bottle was heated and the steam rose up through the spiral, forcing the bottle to spin.

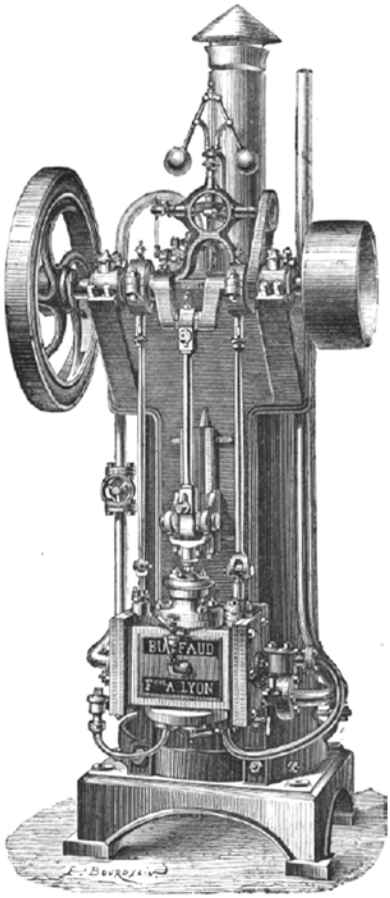

Fig. 7.29 Vertical steam engine [6]

The steam then passed to the coil (labelled *C*, the spirals of which were designed in the opposite direction to those of the bottle-spiral) and expelled the air through *k*. (Immediately after the air had left the spiral through *k*, it closed.) When the system was closed, the condensed steam in the spiral fell to the bottom of the bottle, while the gases produced by heating the water passed through pipe *d* due to the action of the refractory flange *B*. This simple way of obtaining rotary motion as supplied by the bottle shaft *L-T*, was defended by its inventor not only for its simplicity but also for its minimum fuel consumption by making use of all the steam expansion force or its direct action, which avoided leakage or cooling.

The performance of steam engines was improved and power consumption was reduced and ever more factories and builders sprang up, but instead of specialising in building complete engines, they did research and introduced innovations in the parts.

One of the mechanisms that was invented by Watt was the speed regulator using balls which kept the speed more or less constant by means of centrifugal force.

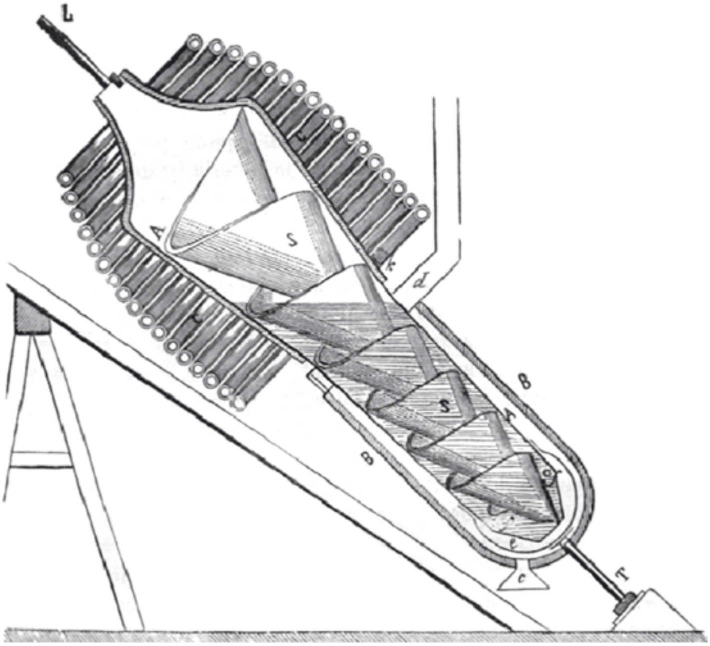

Fig. 7.30 Siemens' steam engine [6]

Figure 7.31 shows a new solution and innovative ball regulator. It also uses balls but these are aided by springs which are connected to the springs, to act as a centrifugal force for a larger or smaller pull on the spring which increases or decreases the speed of the wheel to which the regulator is installed.

On the Development of Transport

The beginnings of the railway can be dated to 1802, when Richard Trevithick patented a high-pressure steam engine to drive a locomotive. Since then steam locomotives evolved very rapidly. In addition a new means of transport arose in towns and cities: the car. Those machines were developed as much as based on mechanism designs as shown in the examples in Figs. 7.32 and 7.33.

On Automatic Astronomical Devices

In this field, we cannot fail to mention "Herschel's Great Telescope". There is a letter by Herschel from 1796, where he accepted a commission to build two telescopes for the King of Spain. The telescope was completed a year later and it was

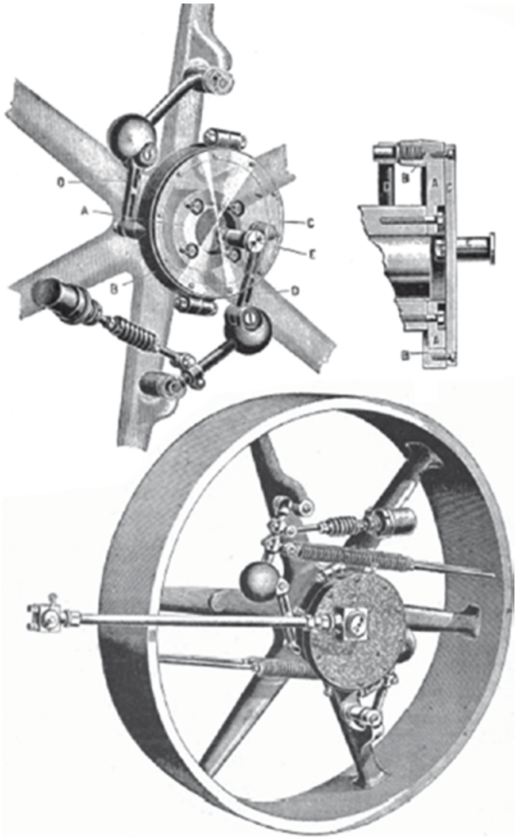

Fig. 7.31 May regulator [106]

installed in the Royal Observatory in Madrid. It was two feet in diameter with a 25 ft focal length, and it was considered the best of its time. Thus, the observatory became part of an up-and-coming branch of astronomy called cosmology and was equipped with one of the world's best telescopes: number one in optical quality in Herschel's opinion and second in size.

Figure 7.34, from the paper entitled "Industrial Archaeology: From the seventeenth to the twenty-first century. Reconstruction of Herschel's Telescope", is indicative of the size of the mechanical device of which the telescope was part. It was supported on a unique circular base-frame comprising oak columns and beams. The tube was suspended at one of its ends by a block and tackle and supported at its highest point on a crossbeam, the other end being supported on the base. The observer could rotate the whole frame as well as vary the inclination of the tube, which were the main movements possessed by the telescope. Figure 7.35 shows some of its mechanisms.

We also have evidence of the improvements the inventor made to the mirrors, enabling him to observe the planet Uranus that had been discovered only a few

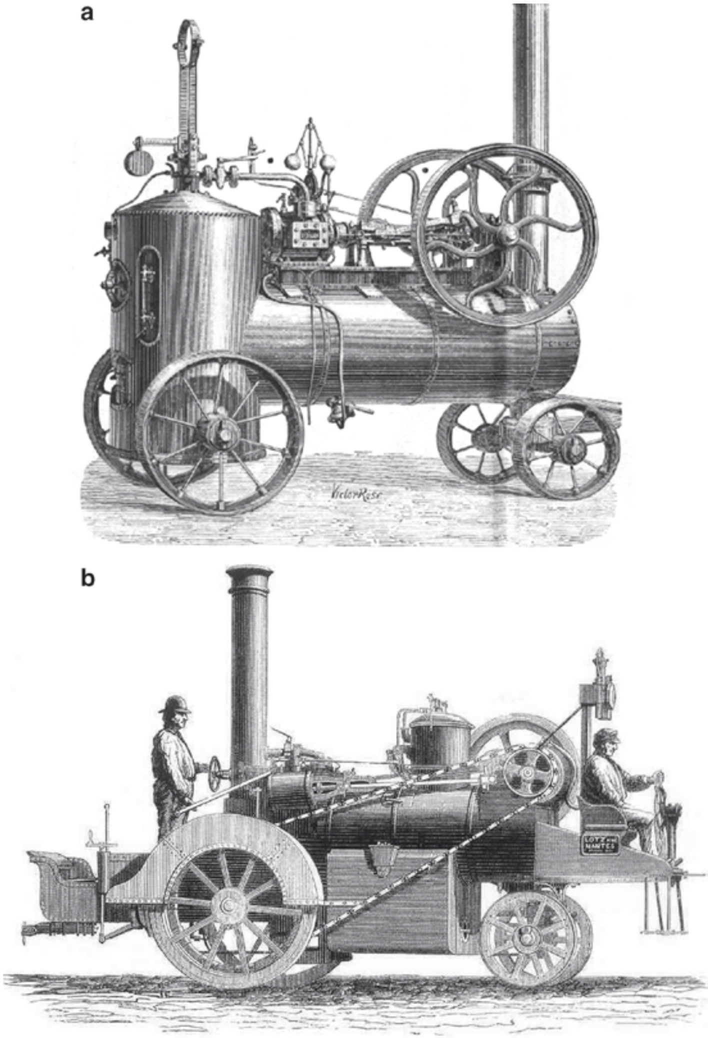

Fig. 7.32 (**a**) 1874 locomotive [6]. (**b**) 1864 Steam vehicle [105]

years earlier. The mechanism incorporated an automatic star tracking system operated by a large clock.

Unfortunately, this telescope was destroyed during the War of Independence in 1808 with just a few scarce remains surviving and a picture of its structure, thanks to some magnificent plates prepared by a naval officer called Mendoza.

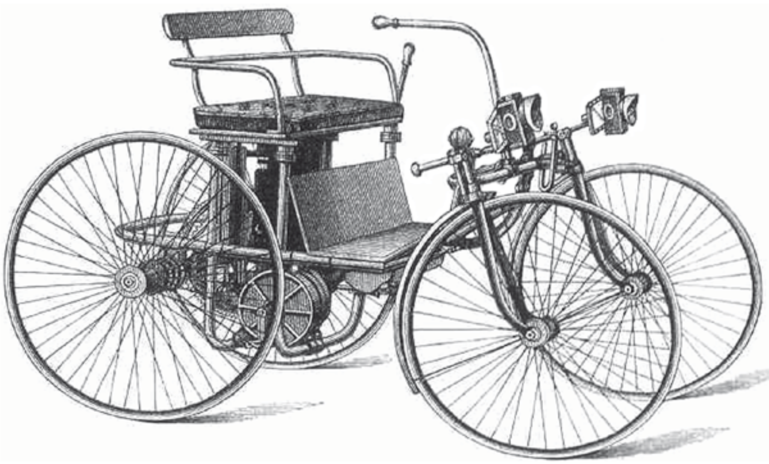

Fig. 7.33 Motor velocipede, 1890 [105]

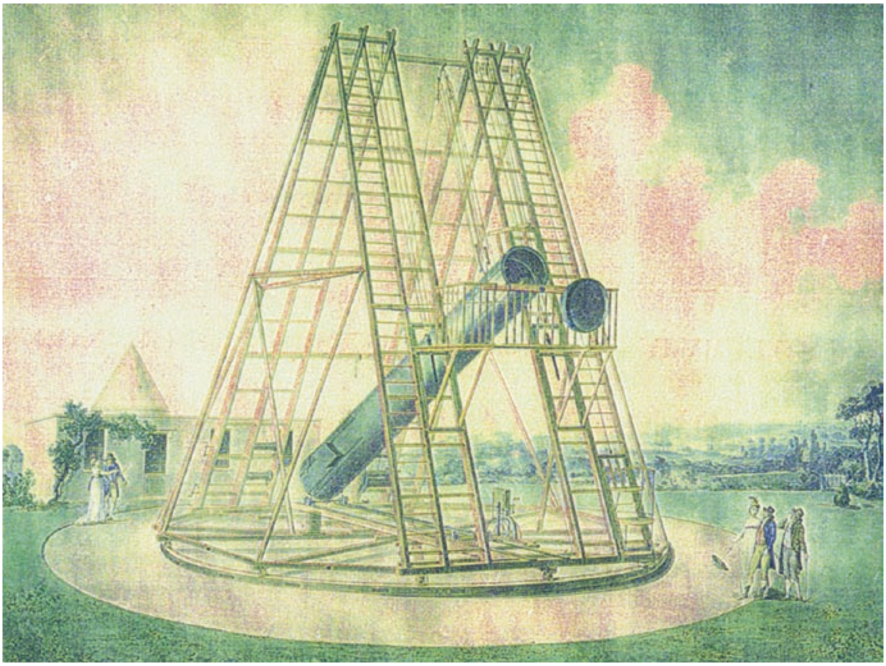

Fig. 7.34 Herschel's telescope [18]

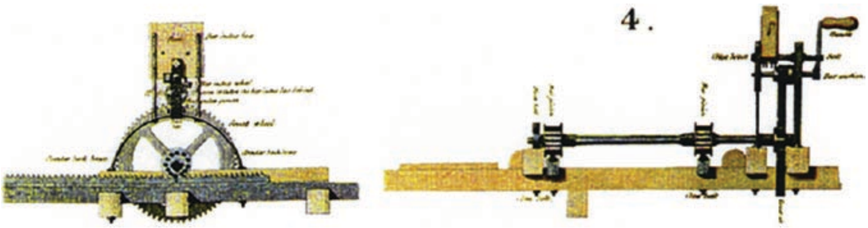

Fig. 7.35 Detail of some of Herschel's telescope's mechanisms [18]